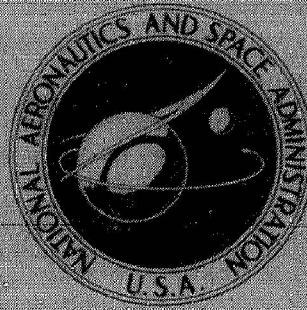


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INVESTIGATION OF TUBING EFFECTS
ON AMPLITUDE FREQUENCY RESPONSE
OF PRESSURE SENSING SYSTEMS
USING NONRESONANT TERMINATIONS

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16. Abstract An investigation was made to determine the effect of tube diameter, tube length, type of material, and area change on the amplitude frequency response of dynamic pressure sensing devices. The devices were mounted a finite distance from the point of disturbance, and nonresonant tube terminations were employed.			
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INVESTIGATION OF TUBING EFFECTS ON AMPLITUDE FREQUENCY RESPONSE OF PRESSURE SENSING SYSTEMS USING NONRESONANT TERMINATIONS

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SUMMARY

An investigation was made to determine the effects of different tubing configurations on the amplitude frequency response of dynamic pressure sensing devices. The devices were mounted a finite distance from the point of disturbance, and nonresonant tube terminations were employed. Data were obtained on 30 different tubing configurations in which four mounting lengths, four termination lengths, three diameters, and two types of tubing material were tested. For each configuration used, the amplitude response at 30 frequencies was recorded for both the reference and test transducers over a frequency range of 20 to 1000 hertz. With a constant mounting length and a constant termination tube length, the flatness of response improved slightly at low frequencies as the tube inside diameter decreased. For constant mounting length and tube diameter, reflections were less pronounced in the low frequency range as the termination tube length was increased. Low frequency response was also improved when an orifice was used to terminate the tube. High frequency response was improved by a decrease in mounting length. Rubber and stainless-steel tubing exhibited the same general response characteristics, although the rubber gave slightly greater attenuation in the higher frequencies. The internal area change introduced by the different transducer mounts and the area change resulting from coupling rubber to stainless steel had no measurable effect on the amplitude frequency response.

INTRODUCTION

The measurement of rapidly varying pressures in wind tunnel testing of air inlets and engines may require that pressure sensing devices be connected to the measuring

point through a finite length of connecting tube. This is primarily due to model space limitations, high-temperature problems, and particle impingement damage considerations.

Pressures may be measured by a resonant system such as that shown in figure 1. If the mounting length is short enough so that the frequencies to be measured are well below the first resonant frequency of the mounting tube (see refs. 1 and 2), these measurements will be reasonably accurate. However, in some types of wind tunnel tests, a mounting length of 6 inches or greater is required. With long mounting lengths, a pressure wave entering the tube and traveling to the transducer is reflected back toward the source and continues to oscillate back and forth in the tube. This organ pipe effect causes a tube resonance with a wavelength equal to four times the tube length, provided that the end volume is negligible. The result is erroneous amplitude and phase measurements. In addition, amplification of the pressure near the resonant frequency may destroy the transducer. Resonance can be prevented by providing a constant-area tube extending beyond the transducer (see fig. 1). The added tube is called the termination tube, and the resulting pressure measuring system is called a nonresonant system. If the termination tube is infinitely long, there will be no resonance because the pressure pulse entering the tube will continue to travel indefinitely. As a wave travels through the termination tube, attenuation occurs because of viscous effects. This attenuation may be sufficiently high so that a reflected wave would not cause significant error, in which case, an intermediate-length termination tube can be used. The total error for the nonresonant tube system is a combination of the error due to attenuation and that due to reflection from the closed end of the tube. For the same transducer mounting length, the total error for the nonresonant system is less than the resonance error caused by terminating the tube at the transducer.

The following are idealized requirements for a nonresonant-type system, as established in reference 3:

- (1) The cross-sectional area at all points in the system must be constant.
- (2) The tube internal passage must be smooth since sharp edges, burrs, steps, voids, or discontinuities create standing waves, resonance, and dynamic distortion.
- (3) All joints must be carefully made to ensure that no pressure leaks exist.

In an actual wind tunnel model, it is necessary to make compromises in the tubing configuration used in order to comply with restraints imposed by the model and to minimize the installation effort. This brief investigation was conducted to determine the sensitivity of nonresonant measuring systems to mounting length, termination length, tube diameter, and tube material.

APPARATUS AND PROCEDURE

The effects of the following factors on the frequency response of pressure sensing systems using nonresonant terminations were measured:

- (1) Mounting tube length, termination tube length, and mounting and termination tube diameter
- (2) Termination tube end treatment (open, closed, or terminated in an orifice)
- (3) Area change imposed by different transducer mounts
- (4) Area change at transition from a hard line to a flexible line
- (5) Termination tubes using a combination of hard and flexible tubing (Flexible tubing is desirable where nonresonant termination tubes are used with an oscillating rake.)
- (6) Termination tubes consisting of rubber tubing only

The various pressure sensing system configurations tested are listed in table I.

A schematic diagram of the pneumatic test setup used is shown in figure 2. The pressure source consisted of a heavy-duty high-power acoustic driver (designed for public address system speakers) with a uniform frequency response from 80 to 12 000 hertz, a voice coil impedance of 16 ohms, and a sound pressure level of 131 decibels. Directly connected to the driver was a reference cavity containing a flush-mounted miniature piezoelectric pressure transducer having a flat frequency response from 5 hertz to 35 kilohertz. This reference cavity transducer established the base line with which the readings of the transducer in the line were compared. The same type of transducer was used in the reference cavity and in the line. The periodic pressure disturbance was coupled to the transducer in the line by stainless-steel mounting tubes of various lengths and diameters, as listed in table I. Termination tube lengths tested are also listed in table I.

Four different transducer mounts were used in the test. Details of these mounts are given in figure 3. Mount configurations 2 and 3 were used to determine the effect on frequency response of a change in area at the transducer location. In configuration 2, the transducer was positioned to maintain a constant cross-section area equal to that of the termination tube. This caused the transducer to protrude slightly into the airstream. In configuration 3, the transducer was located at a tangent to the inside surface of the termination tube, which introduced an area change.

For tests employing rubber tubing as the termination tube, 1-inch-long stainless-steel adapters were used to couple the tubing to the test transducer mount. Both non-tapered and tapered adapters were used (fig. 4) to determine if area change at this point in the configuration would affect amplitude frequency response.

The electrical configuration used for the nonresonant system tests is shown in figure 5. The transfer function analyzer supplied a variable-frequency sinusoidal signal of constant amplitude to a 35-watt audio amplifier. The amplifier output drove the

periodic pressure generator used to excite the transducer under test. The electrical output of the transducer was amplified and returned to the input of the analyzer where a comparison with the original signal was made. This comparison was a measure of the response of the system under test.

Thirty responses were recorded for the reference and test transducers over a frequency range of 20 to 1000 hertz for each configuration tested. The response for the various configurations was taken as the ratio of amplitude from the transducer in the line to that from the reference transducer and is plotted in the figures as the amplitude ratio.

RESULTS AND DISCUSSION

The results of a test to illustrate the effect of tube diameter on amplitude frequency response are given in figure 6. This figure compares the response for stainless-steel tubing of two different inside diameters. The transducer mounting length was 6 inches and the termination tube length was 20 feet for both cases. Results for the 0.090-inch-inside diameter tube show points of resonance in the low frequency range from 20 to 100 hertz with peaks occurring at 20, 40, 60, 80, and 100 hertz. These resonances indicate that for this diameter tube a 20-foot length does not provide sufficient attenuation to produce nonresonant response in the low frequency range. The high frequency response (above 100 Hz) appears relatively flat to 400 hertz with maximum attenuation occurring at an antiresonance point of 650 hertz. For a 0.055-inch-inside diameter tube, the response was flatter in the range from 20 to 100 hertz because of increased attenuation. The increased attenuation, however, also caused a degradation of amplitude ratio magnitude over the whole frequency spectrum. As in the case of the larger diameter tube, maximum attenuation occurred at 650 hertz.

The effect of termination tube length on amplitude frequency response is shown in figure 7. These responses were obtained using 20- and 40-foot-long stainless-steel termination tubes, a mounting tube length of 12 inches, and tube diameters of 0.186 inch. It is apparent that the 20-foot tube did not behave as a nonresonant termination, as evidenced by pronounced reflections between 20 to 400 hertz. By increasing the tube length to 40 feet, a marked improvement in response is noted between 20 to 400 hertz, even though reflections are still prevalent from 20 to 100 hertz. The response from 400 to 1000 hertz is essentially identical for these termination tube lengths. At frequencies to 700 hertz, the attenuation was less than that which occurred for the systems of figure 6.

The effect of mounting length on amplitude frequency response is shown in figure 8. Mounting lengths of 1, 3, 6, and 12 inches were used with a constant-termination tube length of 20 feet and an inside diameter of 0.090 inch. For all four of the configurations tested, reflections occurred in the frequency range between 20 and 100 hertz, indicating

that the 0.090-inch-inside diameter, 20-foot-long tube did not behave as a nonresonant termination. At higher frequencies, attenuation became more pronounced as mounting length increased. For all configurations having a 12-inch mounting length, the response from 400 to 1000 hertz had a resonant point at 550 hertz and an antiresonant point at 900 hertz. The 550-hertz node corresponds to an open organ pipe effect in which the resonant wavelength is equal to twice the mounting length. Therefore, the 6-, 3-, and 1-inch mounting lengths should have displayed peaks at 1100, 2200, and 6600 hertz, respectively. Attempts to verify the open organ pipe effect for these shorter mounting lengths by increasing the response range to 10 kilohertz were unsuccessful. The acoustic driver could not deliver sufficient power to the system at the higher frequencies, and the results obtained were masked by the transducer noise.

Figure 9 shows the difference in amplitude frequency response between an open and a closed nonresonant termination tube. The configuration had a mounting length of 12 inches, a tube inside diameter of 0.186 inch, and a termination tube length of 20 feet. The only significant difference was the reversal of the resonant and antiresonant reflection frequencies. This effect is analogous to an open or shorted electrical transmission line.

The effect of an orifice at the end of a termination tube is illustrated in figure 10. Mounting tube lengths of 12 inches, termination tube lengths of 40 feet, and tube inside diameters of 0.186 inch were used for both the closed-end configuration and the one having a 0.047-inch-diameter orifice at the end. The figure shows that the amplitude frequency response for both configurations was identical from 90 to 1000 hertz. The orifice provided additional attenuation that improved damping of the lower frequency reflections as compared with the closed tube.

A comparison of the amplitude frequency response for a rubber and a stainless-steel termination tube is shown in figure 11. Mounting tube lengths of 12 inches, termination tube lengths of 20 feet, and tube inside diameters of 0.090 inch were used for this test. The rubber gave slightly greater attenuation in the range from 100 to 1000 hertz. Neither configuration exhibited nonresonant characteristics below 100 hertz, and the resonant points showed an out-of-phase relation with each other.

The frequency at which the amplitude ratio has dropped off 1.5 decibels is shown for three different tubing configurations in figure 12. For a termination tube length of 20 feet, the 0.090-inch-inside diameter rubber tube had a somewhat higher attenuation than that of the same diameter stainless-steel tube for all mounting lengths tested. With a mounting length as long as 12 inches, the amplitude ratio for both the rubber and stainless-steel tubes does not drop below 1.5 decibels until the frequency is above 200 hertz. In comparison, for the 0.055-inch-inside diameter stainless-steel tube and a mounting length of 12 inches, the amplitude ratio drops off 1.5 decibels at frequencies above only 20 hertz.

Tests were also conducted to determine the effect on frequency response of the area change at the transducer mount (fig. 3) and of area change caused by transition from a hard tube to a flexible tube (fig. 4). A comparison of the data for the various configurations tested indicated that no measurable effect on amplitude frequency response resulted from these changes.

SUMMARY OF RESULTS

An investigation was made to determine the effects of different tubing configurations on the amplitude frequency response of dynamic pressure sensing devices. The devices were mounted a finite distance from the point of disturbance, and nonresonant tube terminations were employed. Data were obtained on 30 different tubing configurations in which four mounting lengths, four termination lengths, three diameters, and two types of tubing material were tested. For each configuration used, the amplitude response at 30 frequencies was recorded for both the reference and test transducers over a frequency range of 20 to 1000 hertz. The following observations were made:

1. The flatness of response was improved somewhat at low frequencies by a decrease in tube inside diameter.
2. The response at high frequencies improved as transducer mounting length was decreased.
3. Reflections were less pronounced in the low frequency range as the length of the termination tube was increased.
4. Use of an orifice at the end of a termination tube improved the low frequency response over that of a closed tube.
5. Internal area changes introduced by various transducer mounts had no measurable effect on amplitude frequency response.
6. Rubber and stainless-steel tubing exhibited the same general response characteristics, although the rubber gave slightly greater attenuation in the higher frequencies. The area change resulting from coupling rubber to stainless steel had no measurable effect on the amplitude frequency response.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 19, 1970,
720-03.

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2. Taback, Israel: The Response of Pressure Measuring Systems to Oscillating Pressures. NACA TN 1819, 1949.
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TABLE I. - CONFIGURATIONS TESTED

Mount- ing tube length, in.	Termination tube length, ft		Mounting and ter- mination tube inside diameter, in.
	Stainless steel	Rubber	
1	15, 20	20, 50	0.090
3	15, 20	20, 50	.090
6	15, 20	20, 50	.090
12	15, 20	20, 50	.090
3	20	-----	.055
6	20	-----	.055
12	20	-----	.055
3	20	-----	.186
6	20	-----	.186
12	20	-----	.186
12	^a 20	-----	.186
3	40	-----	.186
6	40	-----	.186
12	40	-----	.186
6	^a 40	-----	.186
12	^a 40	-----	.186
6	^b 40	-----	.186
12	^b 40	-----	.186

^aOpen.

^bWith orifice.

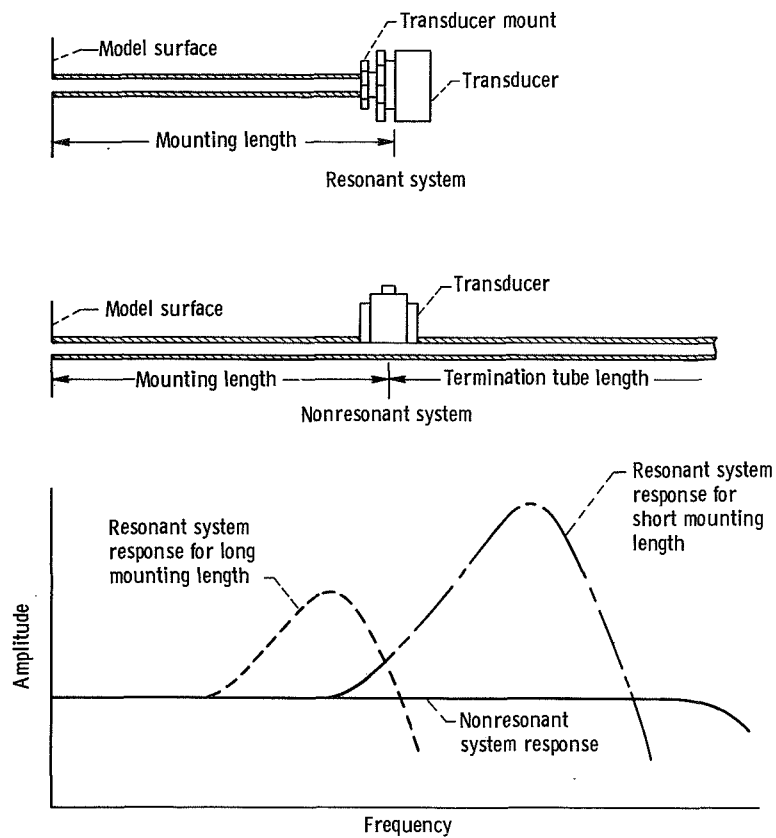


Figure 1. - Resonant and nonresonant pressure sensing systems.

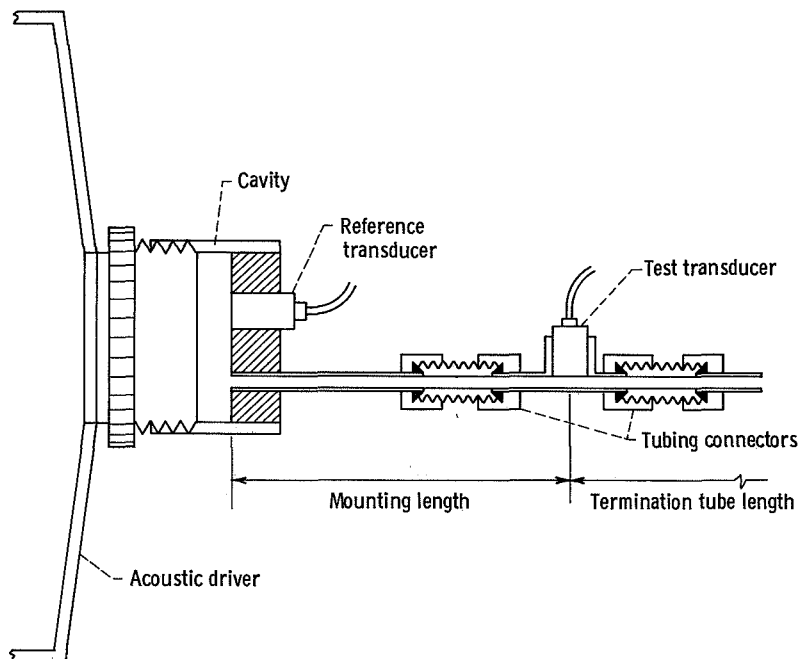
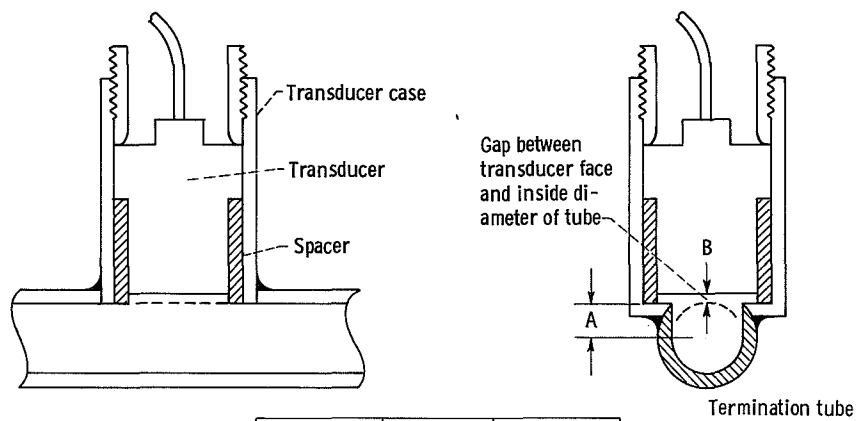


Figure 2. - Pneumatic configuration for testing nonresonant termination tube.



Transducer mount configuration	Tube inside diameter, in.	Section, in.	
		A	B
1	0.055	0.028	0.006
2	.090	.035	^a .003
3	.090	.045	.000
4	.186	.093	.006

^aTransducer face extended into air stream.

Figure 3. - Transducer mount configurations.

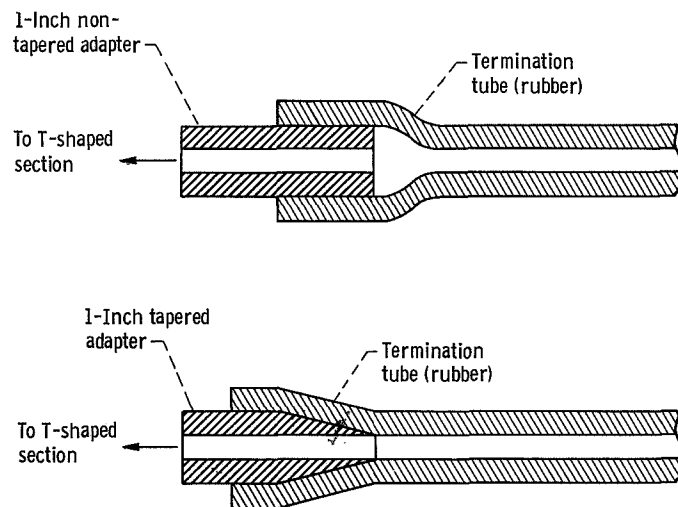


Figure 4. - Stainless-steel adapters used with rubber termination tube.

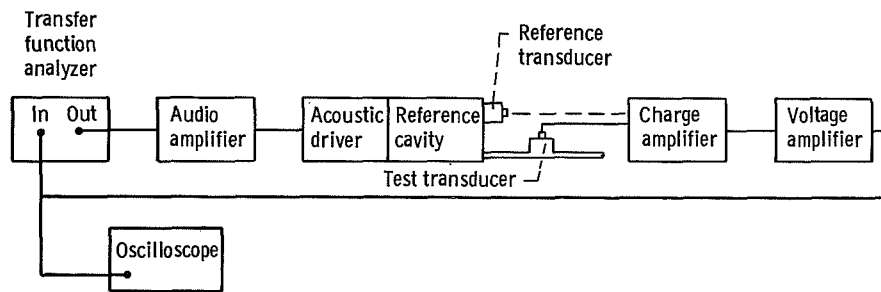


Figure 5. - Electrical configuration for nonresonant termination tube test.

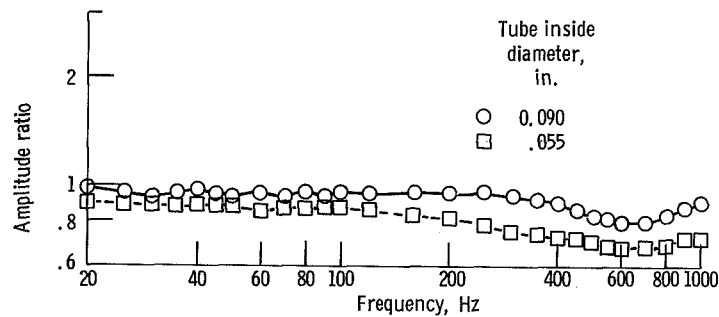


Figure 6. - Effect of tube inside diameter on amplitude frequency response. Mounting length, 6 inches; termination tube length, 20 feet.

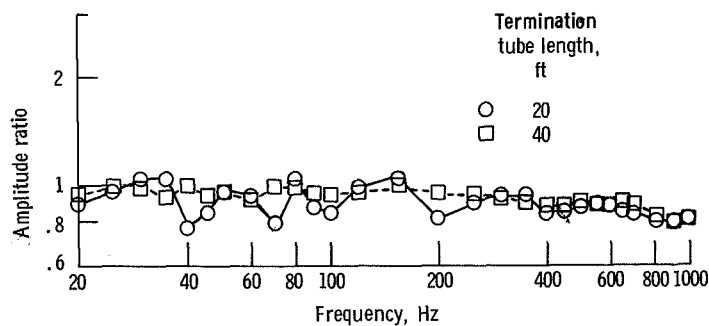


Figure 7. - Effect of termination tube length on amplitude frequency response. Mounting length, 12 inches; tube inside diameter, 0.186 inch.

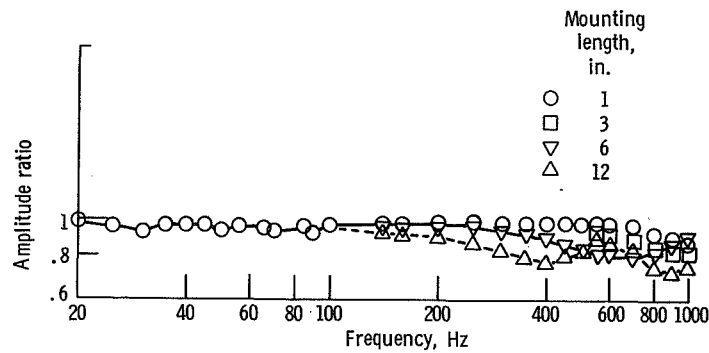


Figure 8. - Effect of mounting length on amplitude frequency response. Termination tube length, 20 feet; tube inside diameter, 0.090 inch. Response for all lengths identical to 100 hertz; response for 1- and 3-inch lengths identical to 500 hertz.

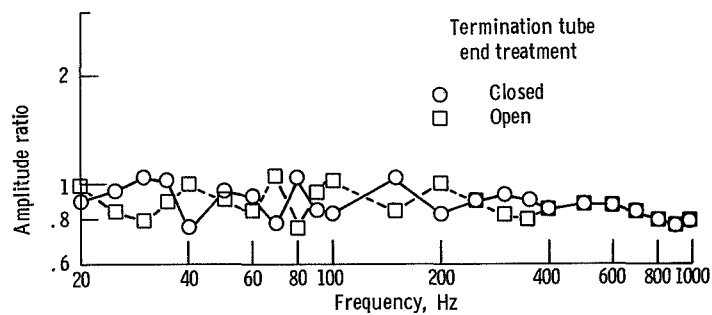


Figure 9. - Effect of open as opposed to closed termination tube on amplitude frequency response. Termination tube length, 20 feet; tube inside diameter, 0.186 inch; mounting length, 12 inches.

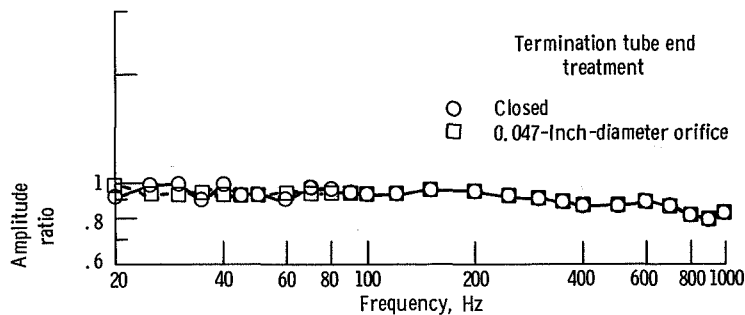


Figure 10. - Effect of orifice on amplitude frequency response. Mounting length, 12 inches; tube inside diameter, 0.186 inch; termination tube length, 40 feet. Both curves identical from 90 to 1000 hertz.

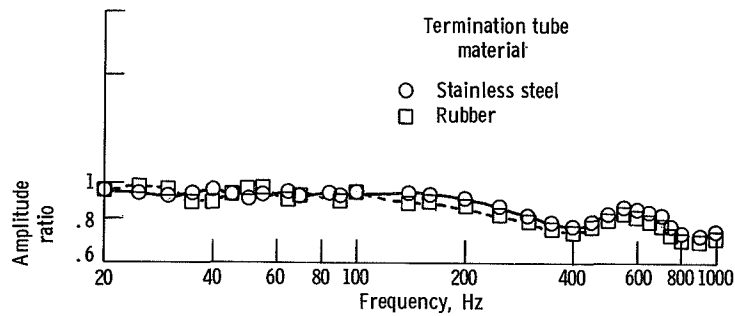


Figure 11. - Amplitude frequency response of stainless steel as opposed to rubber termination tube. Mounting length, 12 inches; tube inside diameter, 0.090 inch; termination tube length, 20 feet.

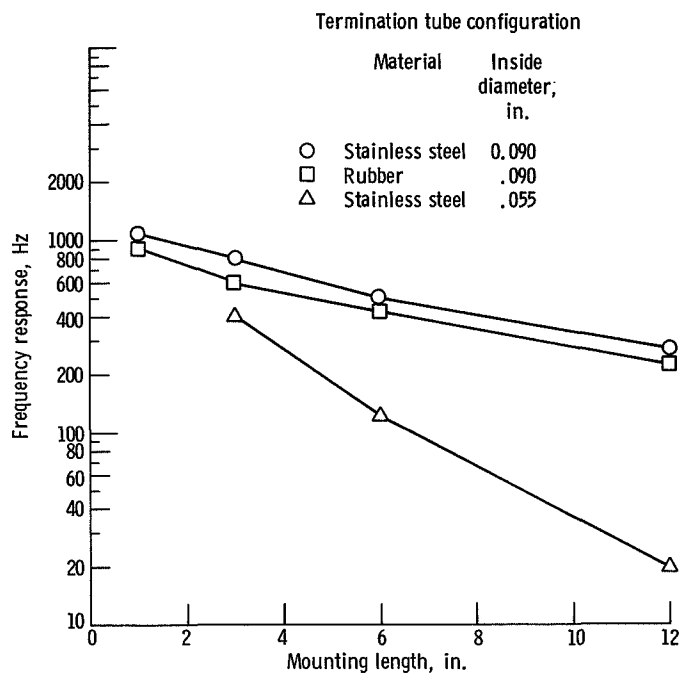


Figure 12. - Breakpoint frequency. Termination tube length, 20 feet.

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